Recent Electroweak Results from DØ

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on behalf of the DØ Collaboration

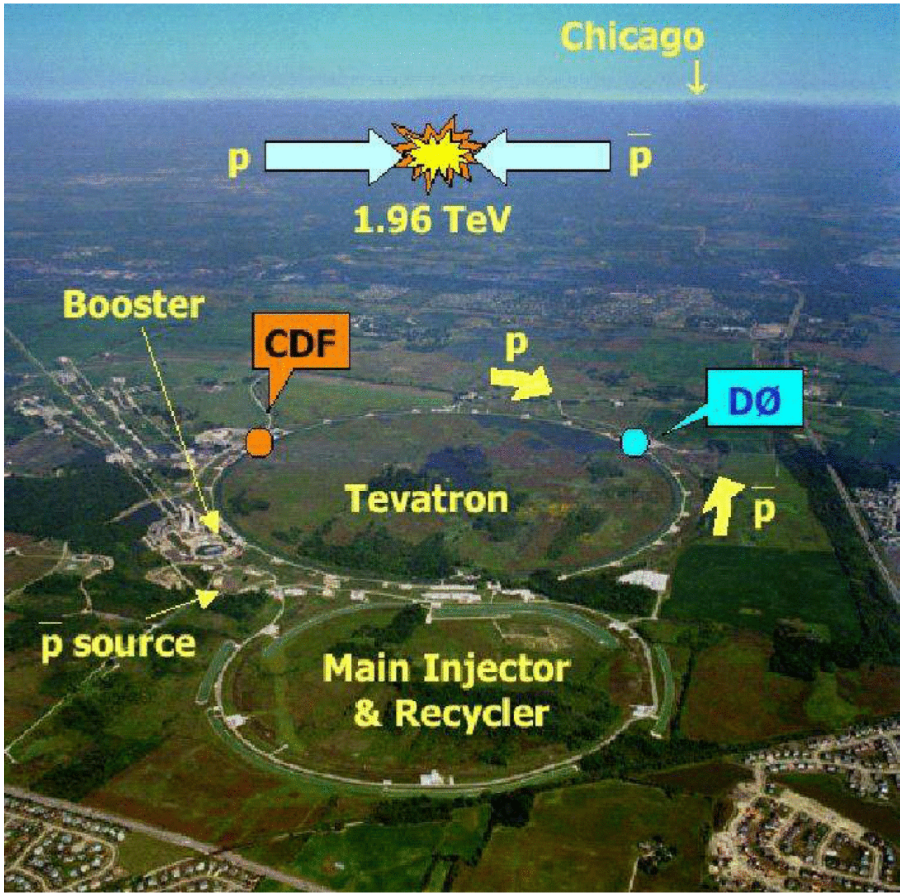
APS Meeting
April 17, 2005

Outline

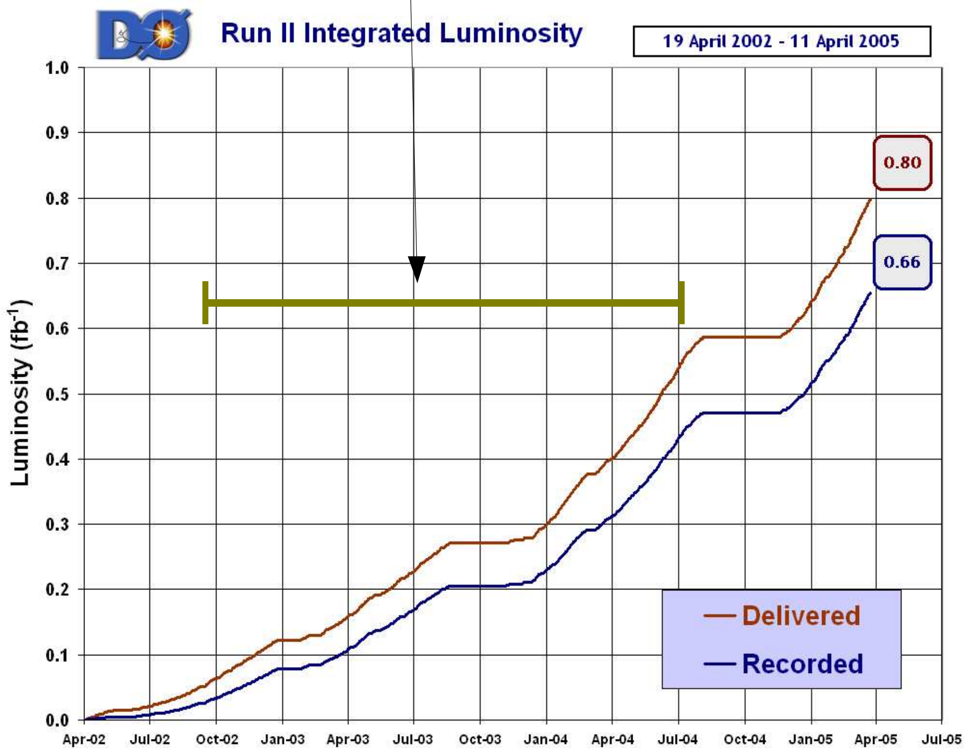
- The Tevatron at Fermilab and the DØ experiment
- $\sigma \times$ Br ($Z \rightarrow \ell\ell$) ℓ = e, μ, τ
- $Z/\gamma^* \rightarrow ee$ Differential Cross Sections
- $\sigma \times$ Br ($W \rightarrow \ell\nu$) ℓ = e, μ
- W width
- Diboson Analyses

More details on results available at
DØ Latest Results Webpage
http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

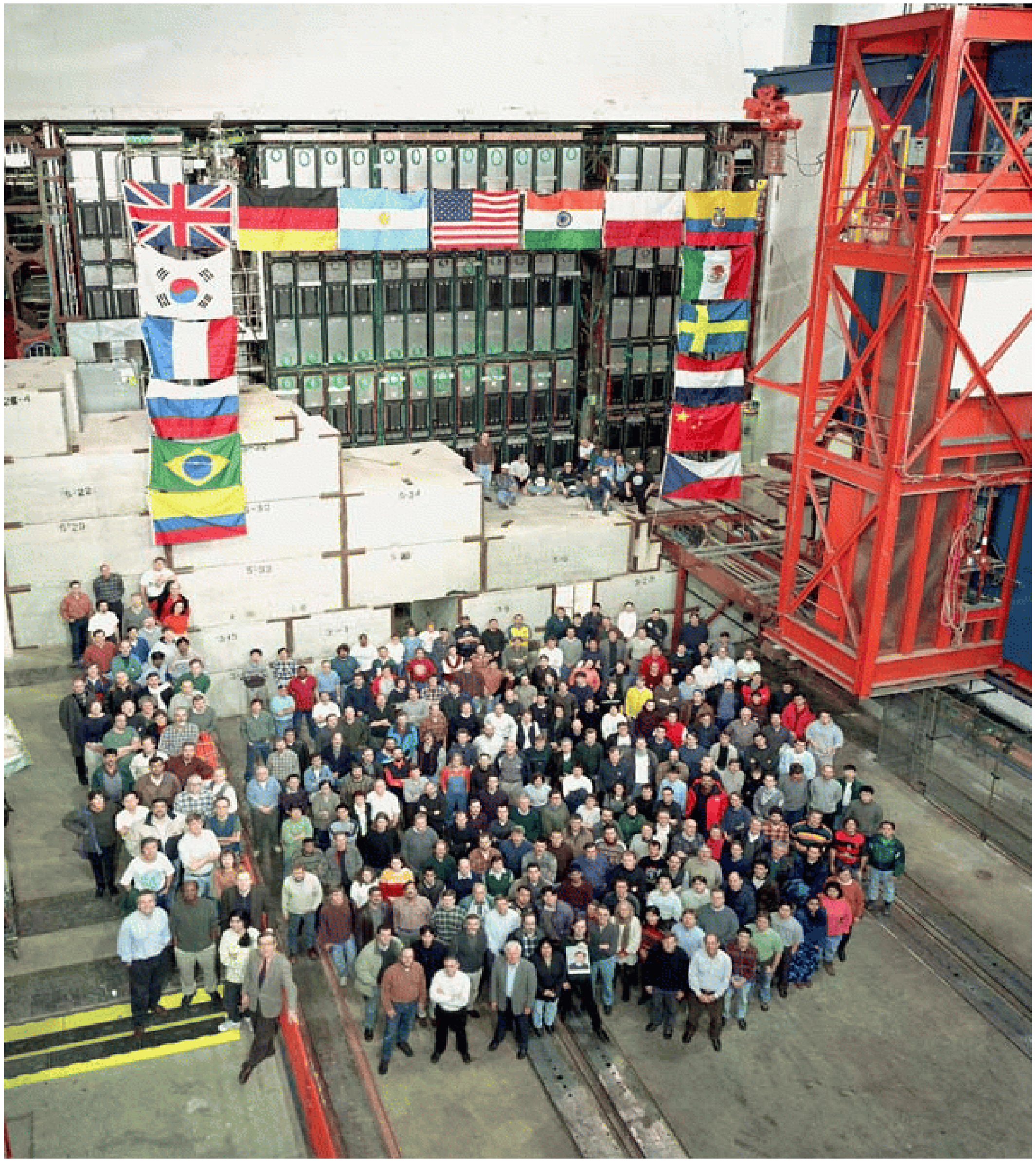
Run II at the Tevatron



- $p\bar{p}$ collisions at
  $\sqrt{s} = 1.96$ TeV
- Recorded $\int\mathcal{L} \sim 0.7\ \mathrm{fb}^{-1}$ to date
  - Results shown in this talk are on $\int\mathcal{L} \sim 0.2\text{-}0.3\ \mathrm{fb}^{-1}$
  - Run II expects $\int\mathcal{L} \sim 4\text{-}8\ \mathrm{fb}^{-1}$ delivered

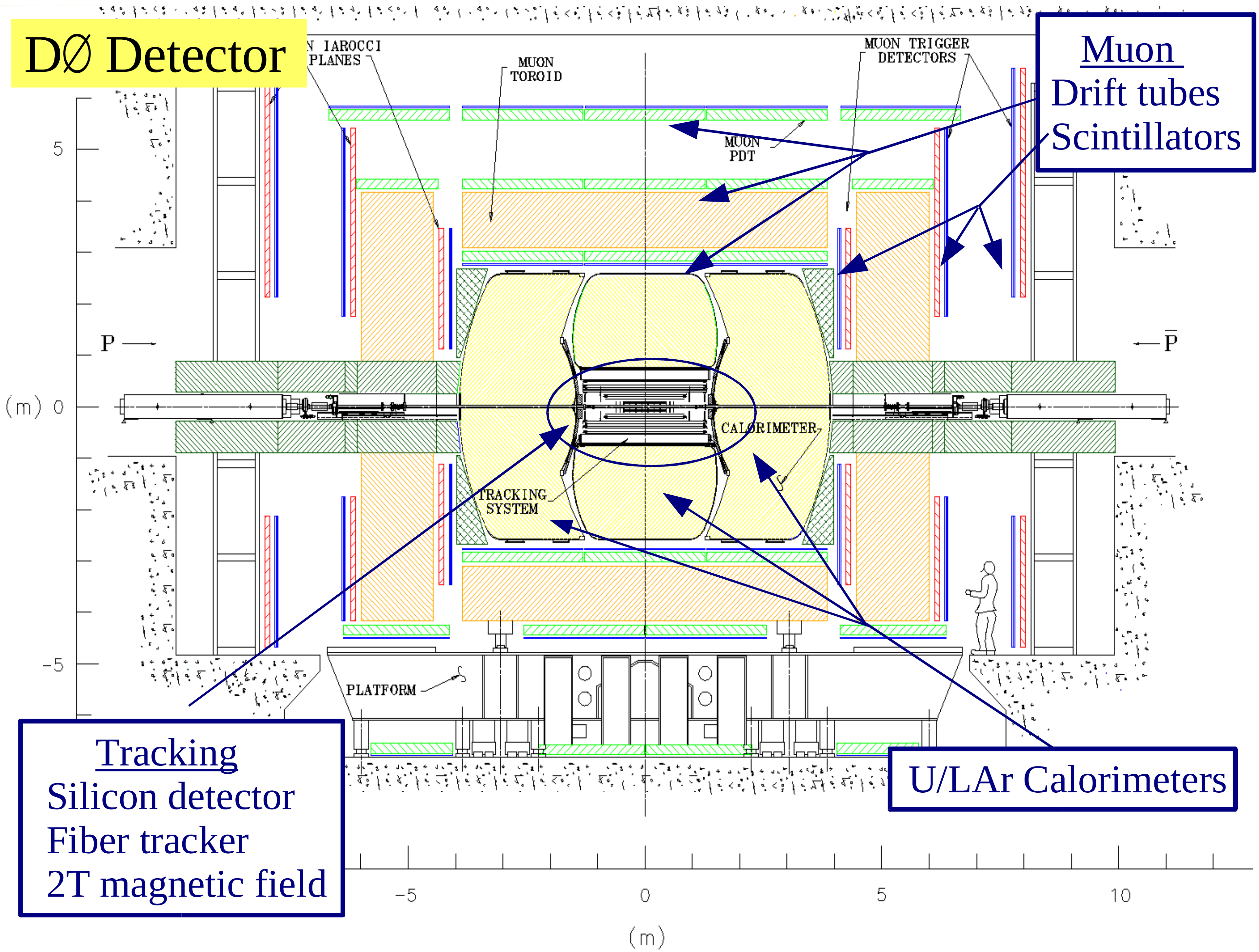


The DØ Collaboration



- 19 countries
- 80 institutions
- 670 physicists

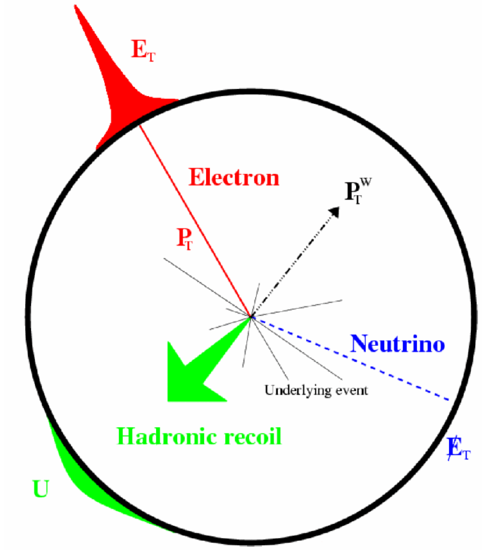
DØ Detector

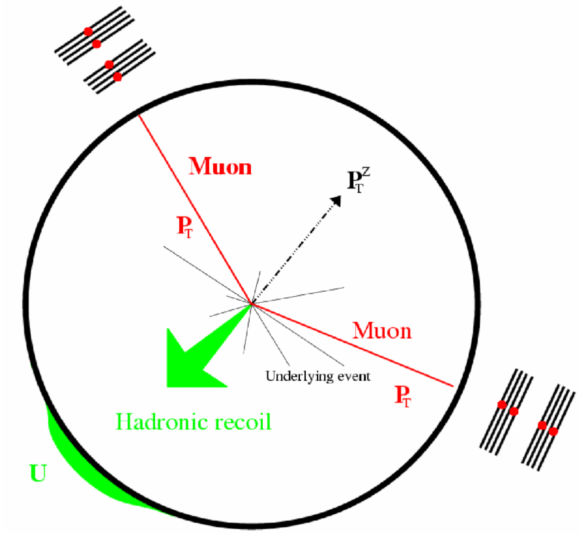

Muon
Drift tubes
Scintillators
N IAROCCI PLANES
MUON TOROID
MUON TRIGGER DETECTORS
MUON PDT
P
P̄
CALORIMETER
TRACKING SYSTEM
PLATFORM
(m)
5
0
-5
10
Tracking
Silicon detector
Fiber tracker
2T magnetic field
U/LAr Calorimeters

W,Z to e or μ Inclusive Cross Sections

<u>Motivation:</u>

- Clean, abundant, and well known signals
- Test of the SM
- Benchmark measurements for the detector
- Can be used to cross check luminosity measurements





<u>Limitations:</u> uncertainties on

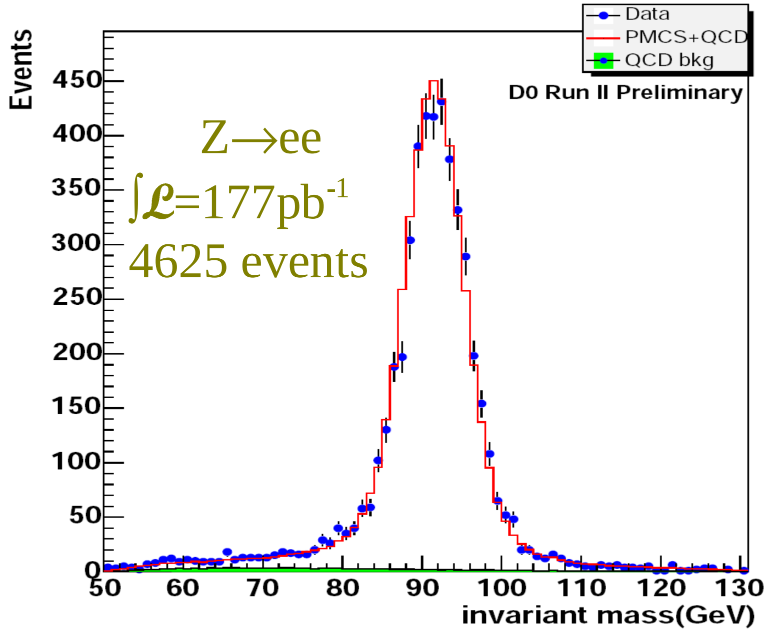
- Luminosity ~ 6.5%
- Parton Distribution Functions (PDFs) ~1.5%
- Others (lepton ID, Z statistics, ...)

Analysis Method

$$\sigma \times Br = \frac{N^{candidates} - N^{background}}{\varepsilon \times Acc \times \int \mathcal{L}}$$

- Look for high p_T e or μ, often with a track match
- Backgrounds:
  - Larger background, such as Multijet or W+jet, estimated from data
  - Smaller background, such as $t\bar{t}$ or diboson, estimated from MC
- Measure efficiencies from data
- Determine Acceptance from Monte Carlo and detector simulation

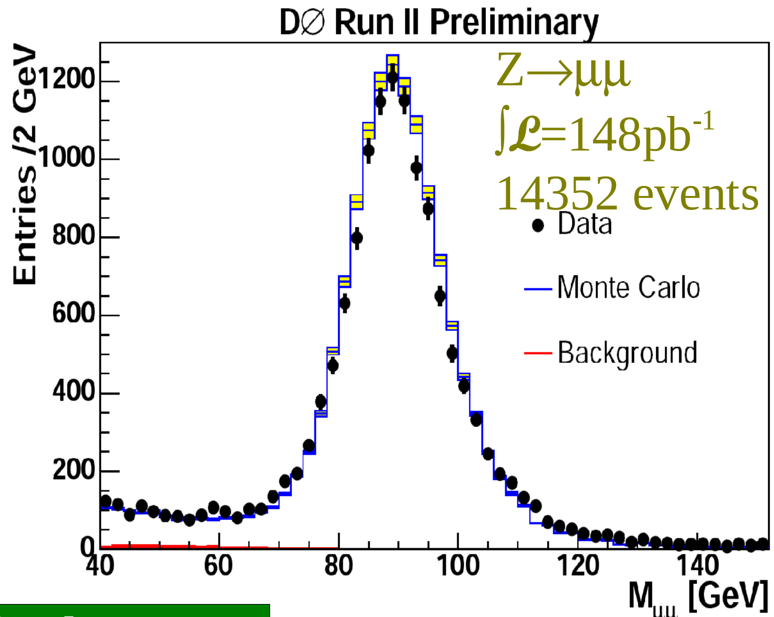
Z to e^+e^- or $\mu^+\mu^-$



- Require 2 high p_T isolated leptons

Main backgrounds:

- Multijet events ~2% (Z→ee)
- $b\bar{b}$, $Z\to\tau\tau$ ~0.5% each ($Z\to\mu\mu$)



Main Syst. Uncertainties:

- EM ID ~2.9% (Z→ee)
- PDFs ~1.8% ($Z\to ee$, $Z\to\mu\mu$)
- Detector modelling ~1% ($Z\to\mu\mu$)

See talk by Gavin Hesketh in J11

DØ Prelim: $\sigma \times Br(Z\to ee) = 264.9 \pm 3.9_{stat} \pm 9.9_{syst} \pm 17.2_{lumi}$ pb

DØ Prelim: $\sigma \times Br(Z\to \mu\mu) = 291.3 \pm 3.0_{stat} \pm 6.9_{syst} \pm 18.9_{lumi}$ pb

$Z \rightarrow \tau^+\tau^-$

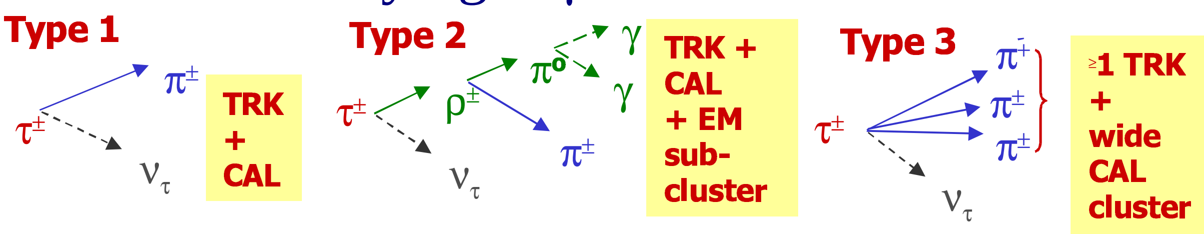
- First time measured with $p\bar{p}$

See talk by Yuri Gershtein in J11

- Establishes τ ID
  - Important for other analyses

Selection:

Isolated τ decaying to μ back to back with:



NN used for τ ID

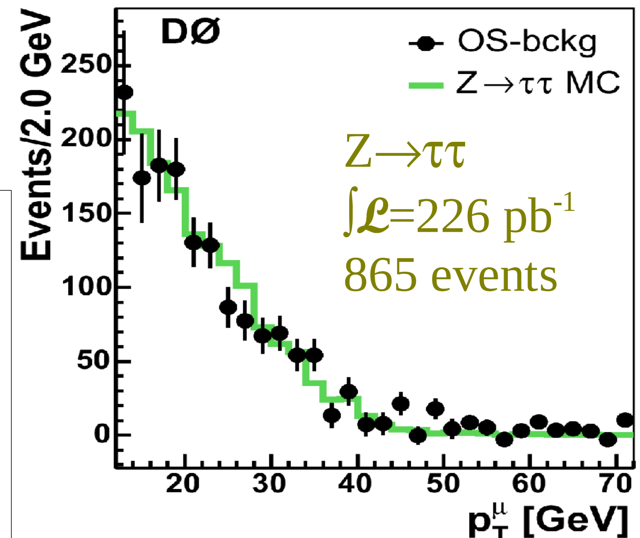
Main backgrounds:

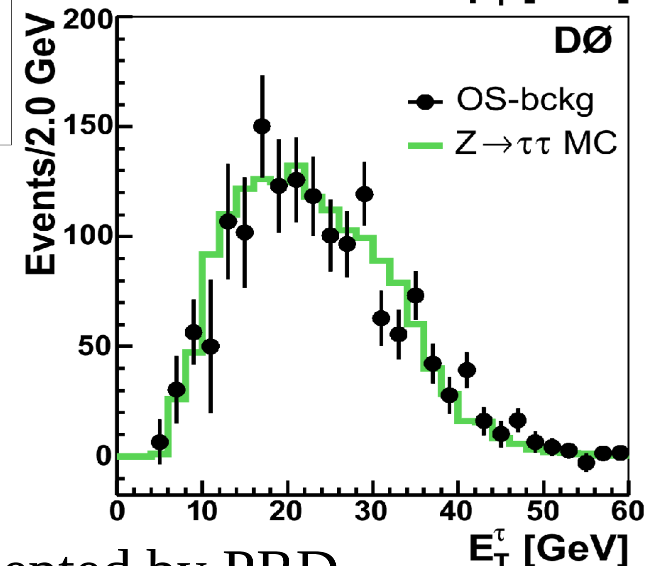
- QCD ~49%, W/Z→μ+jet ~6%

Main Systematic Uncertainties:

- Trigger 3.5%, QCD BG 3.5%

$\sigma \times Br(Z \rightarrow \tau\tau)$: $237 \pm 15_{stat} \pm 18_{sys} \pm 15_{lumi}$ pb





Accepted by PRD
hep-ex/0412020

$\frac{d\sigma}{dY}(Z/\gamma^* \to e^+e^-)$

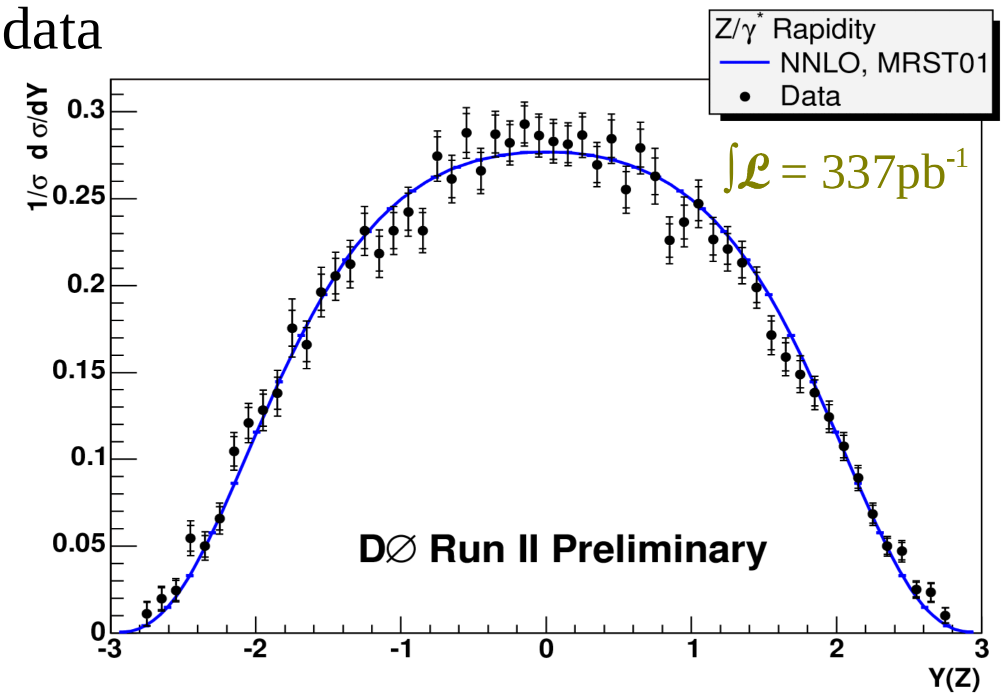
Rapidity distribution

$$x_{1,2} = \frac{M_Z}{\sqrt{s}} e^{\pm Y}$$

- Initial $q\bar{q}$ with $\Delta x \neq 0$ boosts boson
  - Large |Y| probes quarks with low x (~0.001)and high Q^2 ($\sim M_Z^2$)
  - Different systematics than jet data
- Makes use of wide $|\eta_D|$ coverage of DØ calorimeter

Main Syst. uncertainties:

	|Y|~0	|Y|>2
– PDFs	~1.5%	- 10%
– Efficiencies:	~1.2%	- 20%



See talk by Ming Yan in J11

*NNLO Curve from Anastasiou, et. al., 2004

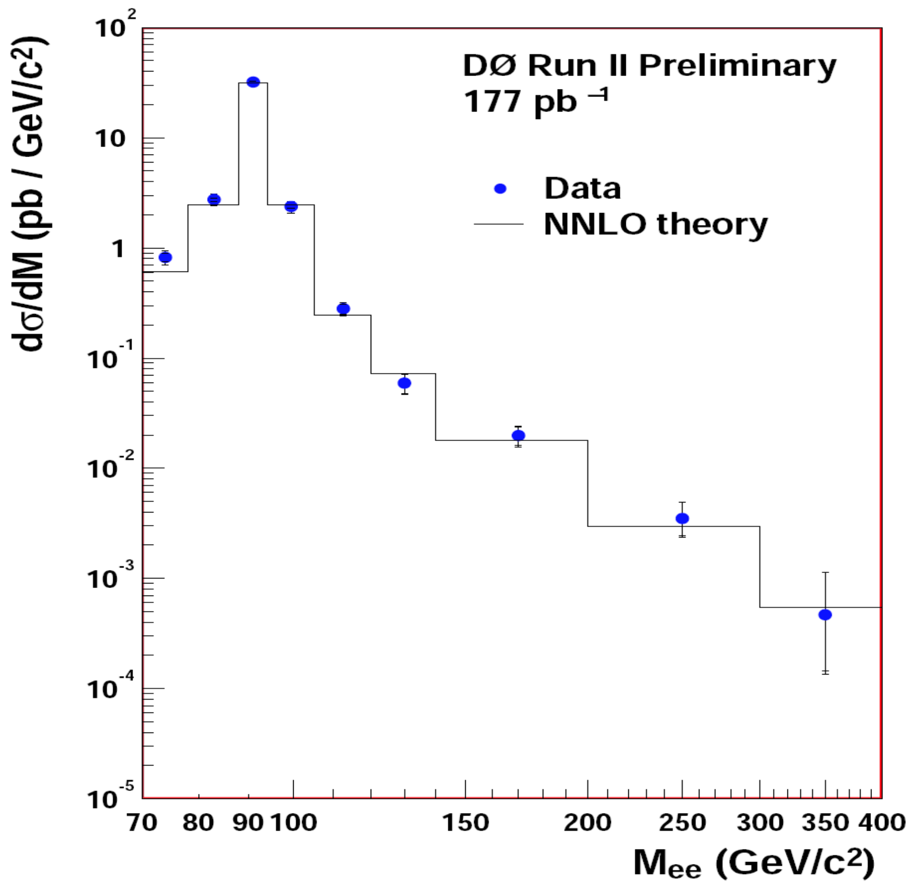
$\frac{d\,\sigma}{d\,M}$ $(Z/\gamma^{*} \rightarrow e^{+}e^{-})$

- Distribution sensitive to new physics
- Corrected for effects due to
  - Finite detector resolutions
  - Acceptance
  - QED radiative corrections

Main BG: Multijet events which fake EM ID ~ 1%

Main systematic uncertainties:

- background estimate
- PDFs
- detector modeling
- Boson p_T in MC

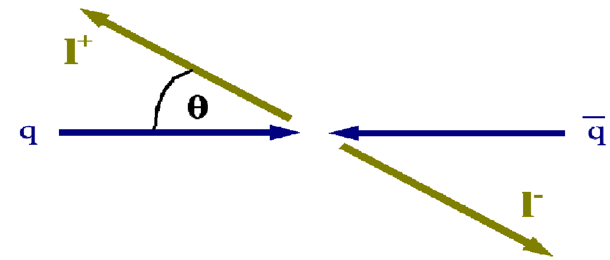


*NNLO curve from
Hamberg, van Neerven, and Matsuura 1991.

Z/γ*→e$^+$e$^-$ Forward-Backward Asymmetry

An extension of $\frac{d\sigma}{dM}$ analysis

$$\frac{d\sigma}{d(\cos\theta)} = \alpha\left(\beta\left(1+\cos^2\theta\right) + A_{FB}\cos\theta\right)$$



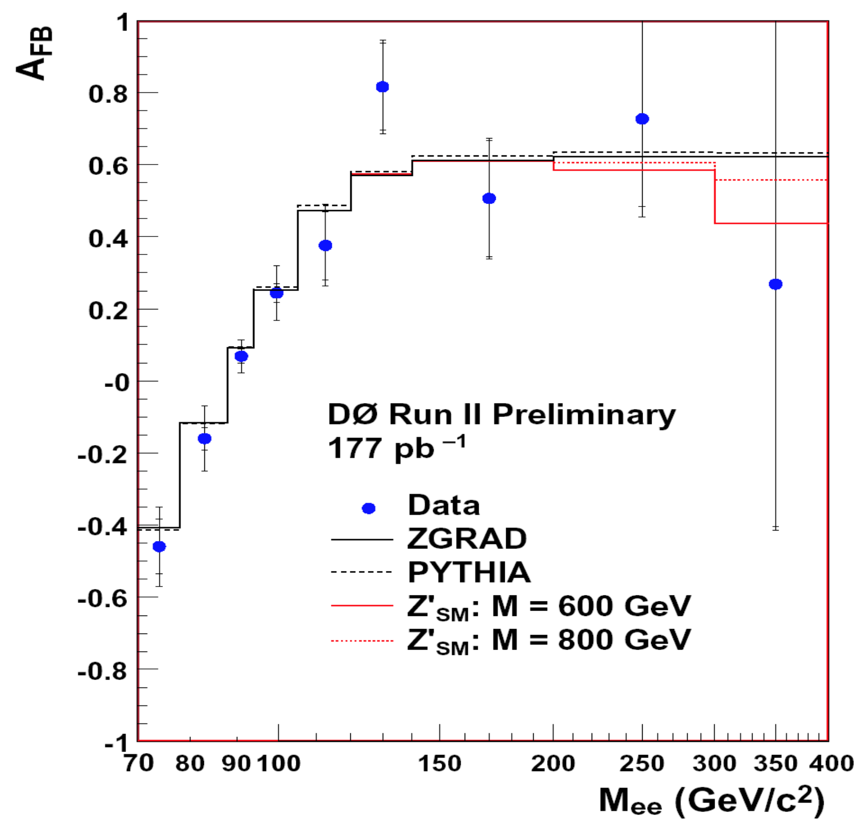
The vector and axial-vector nature of

fermion-Z couplings leads to

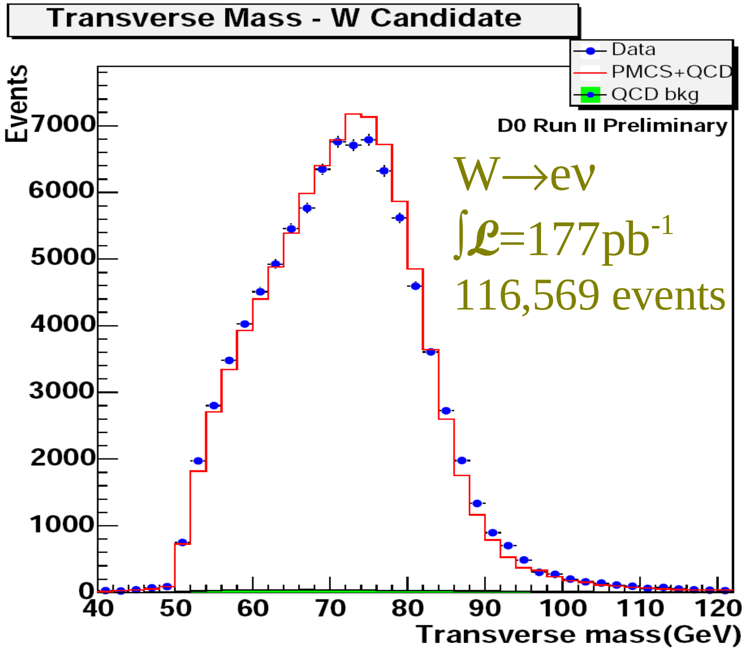
asymmetry in lepton production angle

$$A_{FB} = \frac{\int_0^1 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta) - \int_{-1}^0 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta)}{\int_0^1 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta) + \int_{-1}^0 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta)}$$

- A_{FB} vs. mass has different sensitivity to u, d quarks
- Mix of vector and axial-vector couplings change with mass



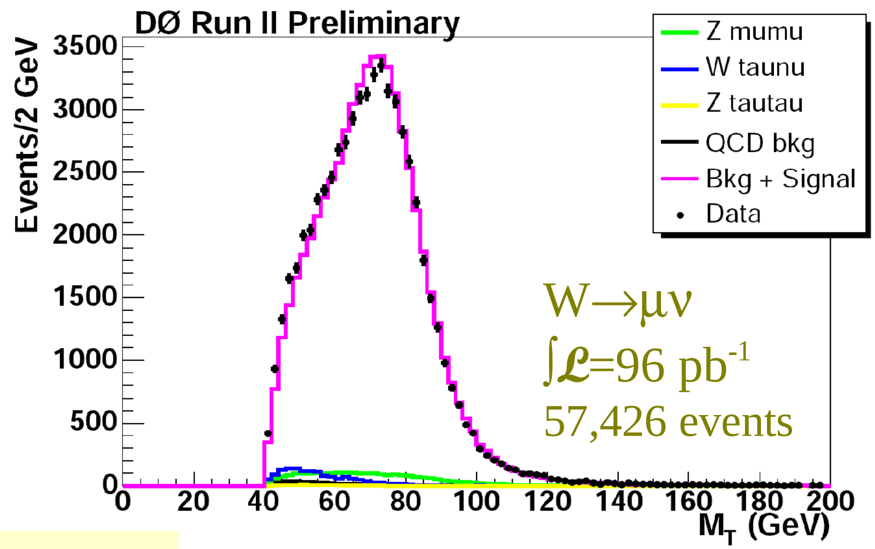
W to eν or μν



- Single high p_T isolated lepton(>15-25 GeV)
- Large $\not{E}_T$ (> 15-25 GeV)

Main backgrounds:

- – Multijet events ~30% (W→eν)
- – $b\bar{b}$, $Z\to\tau\tau$ ~3-4% (W→μν)



Main Syst. Uncertainties:

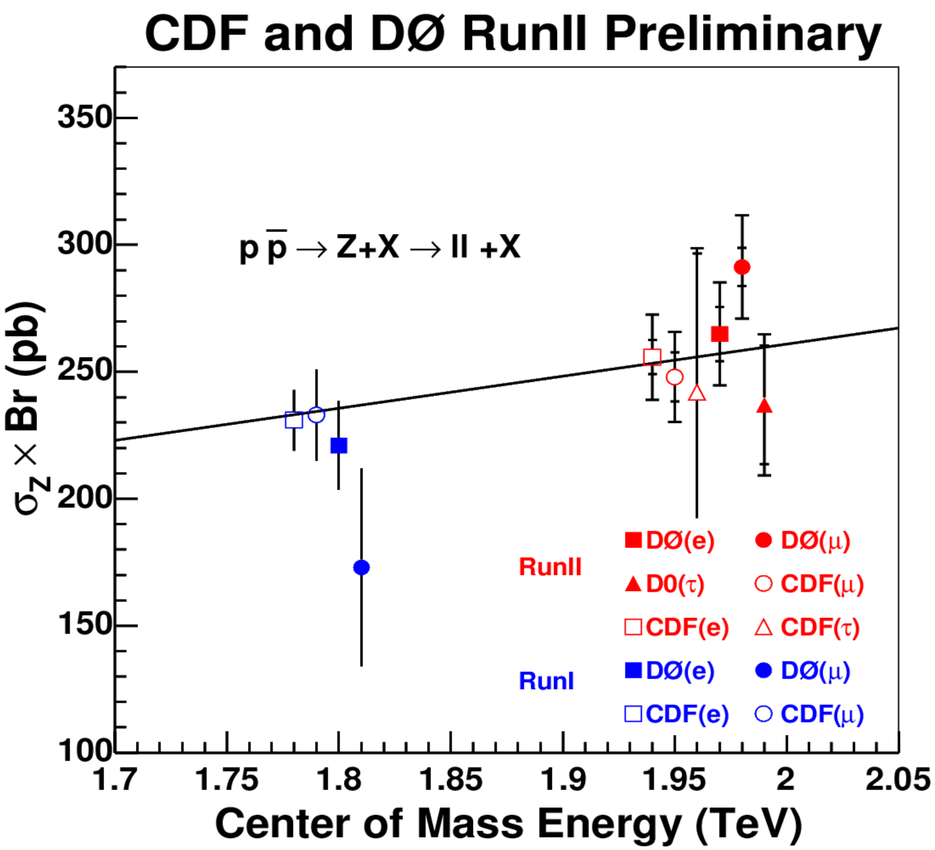
- PDFs ~1.4%
- ε × Acceptance (excl. pdf) ~1.5% -2%

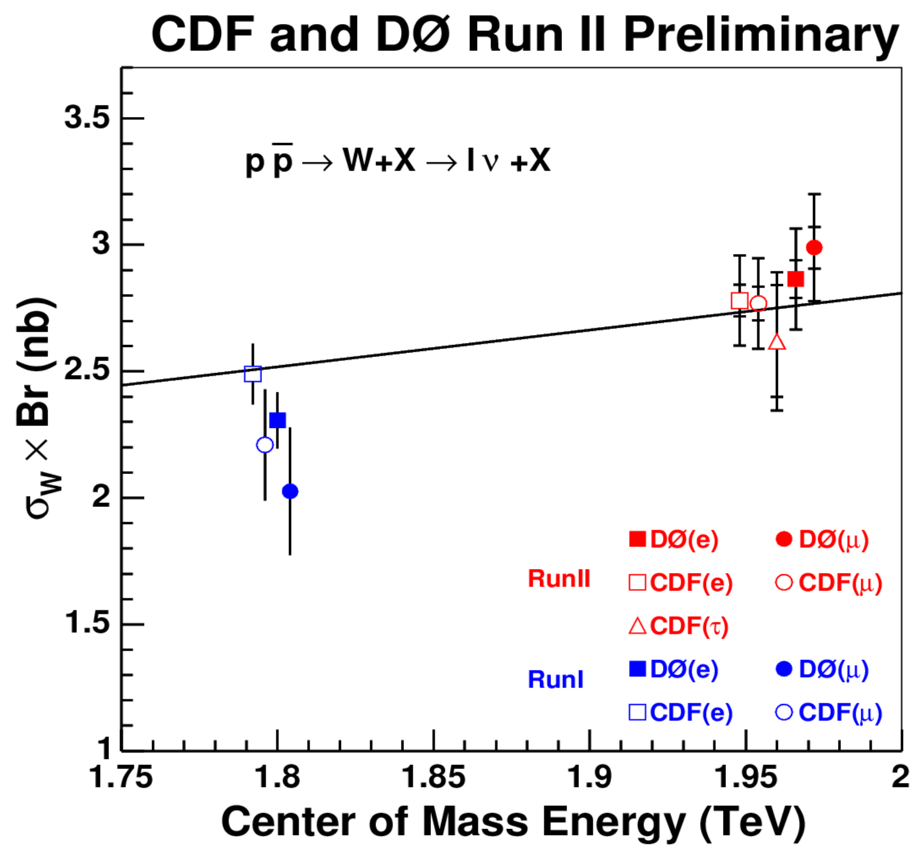
See talk by Gavin Hesketh in J11

$\sigma \times Br(W\to e\nu)$: $2865 \pm 8.3_{stat} \pm 76_{syst} \pm 186_{lumi}$ pb

$\sigma \times Br(W\to \mu\nu)$: $2989 \pm 15_{stat} \pm 81_{syst} \pm 194_{lumi}$ pb

W, Z Cross Section Summary





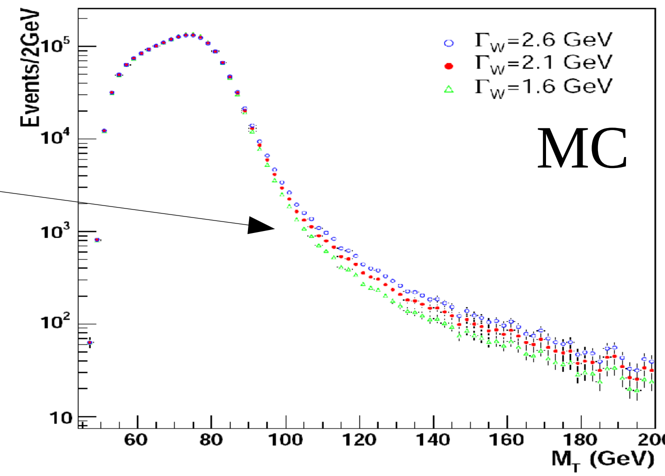
*NNLO curve from Hamberg, van Neerven, and Matsuura 1991.

Direct Measurement of W Width

$W \rightarrow e\nu$; $177 pb^{-1}$ (same as W cross section)

Method

- Generate MC templates with different W widths
- Compare to tail of M_T distribution ($100 < M_T < 200$ GeV)

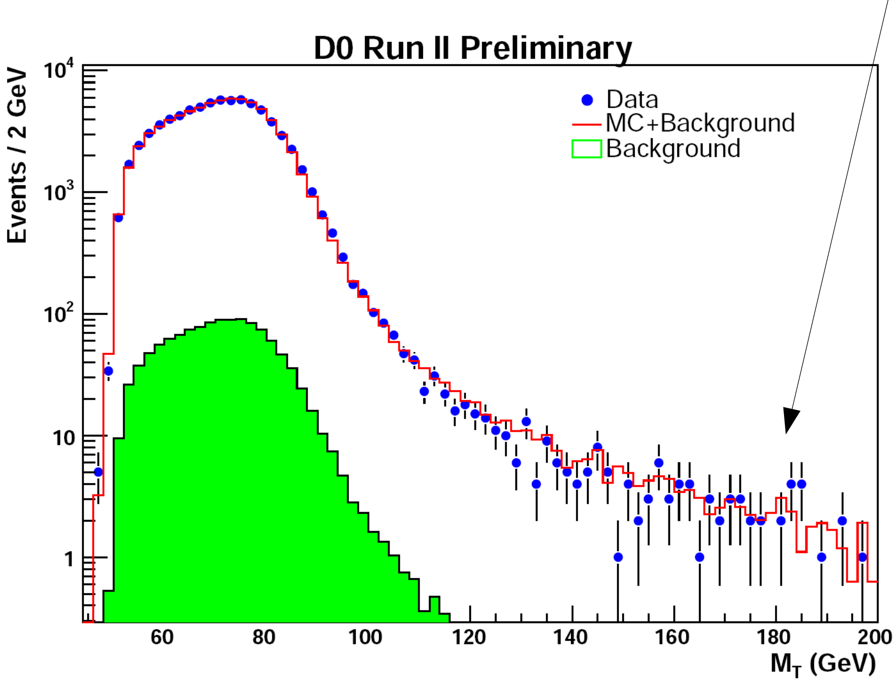


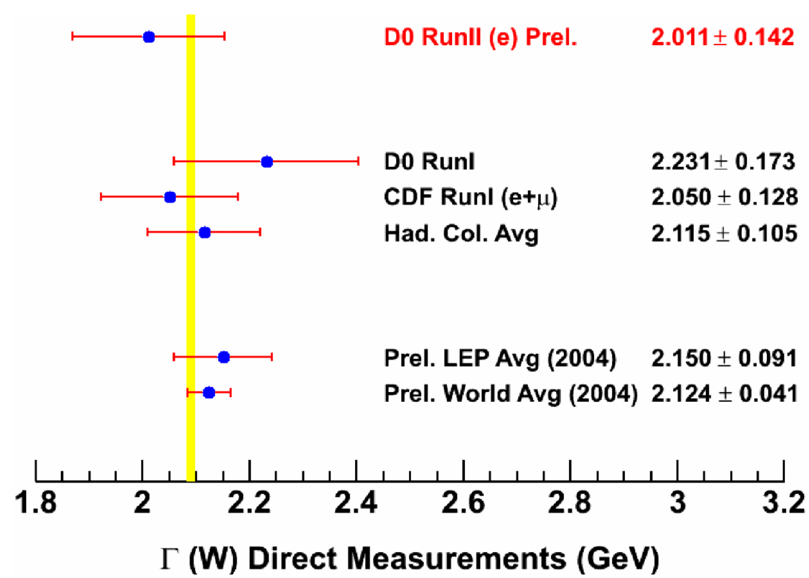
Main Systematic Uncertainties:

- Hadronic response & resolution ~64 MeV
- Underlying event ~47 MeV
- EM resolution ~30 MeV

DØ Preliminary:

$\Gamma_W = 2.011 \pm 0.93$ (stat) ± 0.107 (sys)





Diboson Analyses: Wγ WW WZ Zγ

- Measure Cross sections, test Anomalous Couplings
- Any excess above SM expectations could indicate new physics
- Background for other analyses
  - top pairs
  - Higgs, NP searches
- Look for W,Z decays to final state e or μ
  - Smaller branching ratio than jets in final state, but much less background
- Similar measurements done in Run I and at LEP

Test for AC via L_{eff}:

$$\mathrm{L}_{\mathrm{WWV}} / g_{\mathrm{WWV}} = \boxed{g_{\mathrm{V}}^{1}}(\mathrm{W}_{\mu\nu}^{\dagger}\mathrm{W}^{\mu}\mathrm{V}^{\nu} - \mathrm{W}_{\mu}^{\dagger}\mathrm{V}_{\nu}\mathrm{W}^{\mu\nu}) + \boxed{\kappa_{\mathrm{V}}}\mathrm{W}_{\mu}^{\dagger}\mathrm{W}_{\nu}\mathrm{V}^{\mu\nu} + \frac{\boxed{\lambda_{\mathrm{V}}}}{M_W^2}\mathrm{W}_{\lambda\mu}^{\dagger}\mathrm{W}_{\nu}^{\mu}\mathrm{V}^{\nu\lambda}$$

Where V = Z, γ

In SM: $g^1_V = \kappa_V = 1$

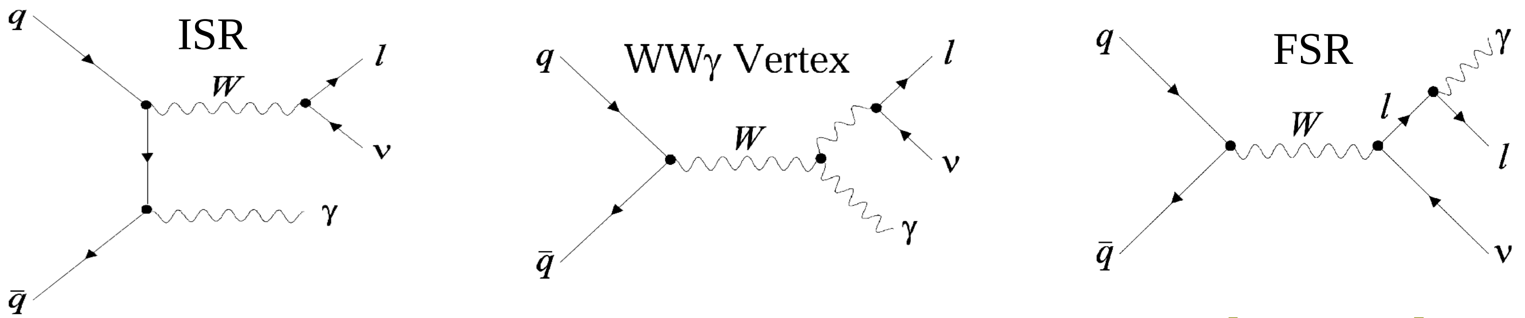
$\lambda_V = 0$

Determine from data:

$\Delta g^1_V = g^1_V - 1$; λ_V; $\Delta\kappa_V = \kappa_V - 1$

Wγ

Three diagrams contribute at LO



- Look for W decays to e or μ
  - p_T, $\not{E}_T$ > ~25 GeV
- Require Central γ with $E_T(\gamma)$ > 8 GeV
- $\Delta R(l\gamma) > 0.7$ (suppress FSR)

$\sigma(p\bar{p} \to l\nu\gamma + X) = 14.8 \pm 2.1$ pb

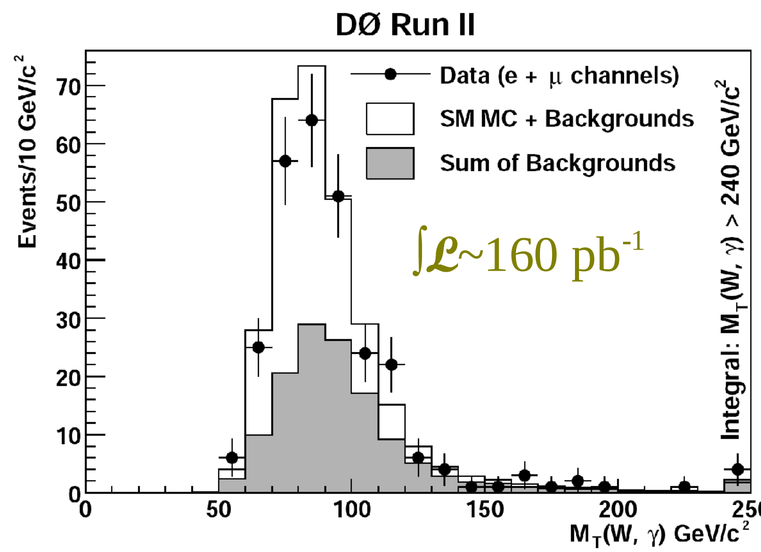
SM* 16.0 ± 0.4 pb

Submitted to PRD Rapid Comm.
hep-ex/0503048

Main Background:

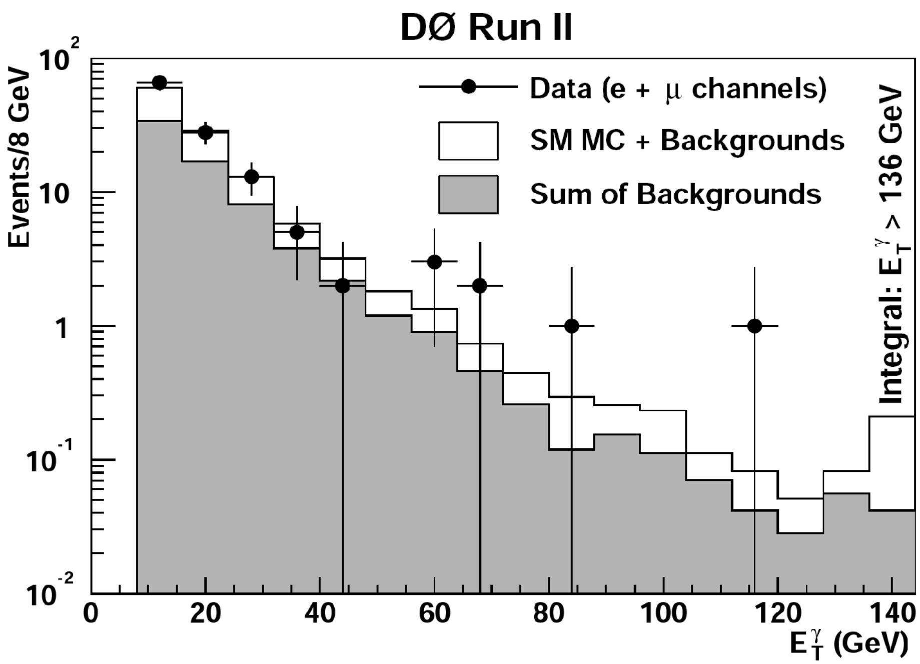
W+j, jet misID'd as γ ~50%

Main Syst. Uncertainty: background estimate



*Baur & Berger, PRD 41, 1476 (1990)

Wγ Anomalous Couplings



- Binned likelihood fit on $E_T(\gamma)$ spectrum gets 1D, 2D limits on $\Delta\kappa_\gamma$ and λ_γ
- Require $M_T(W,\gamma)$>90 GeV to enhance WWγ contribution

1D limits @ 95%C.L.

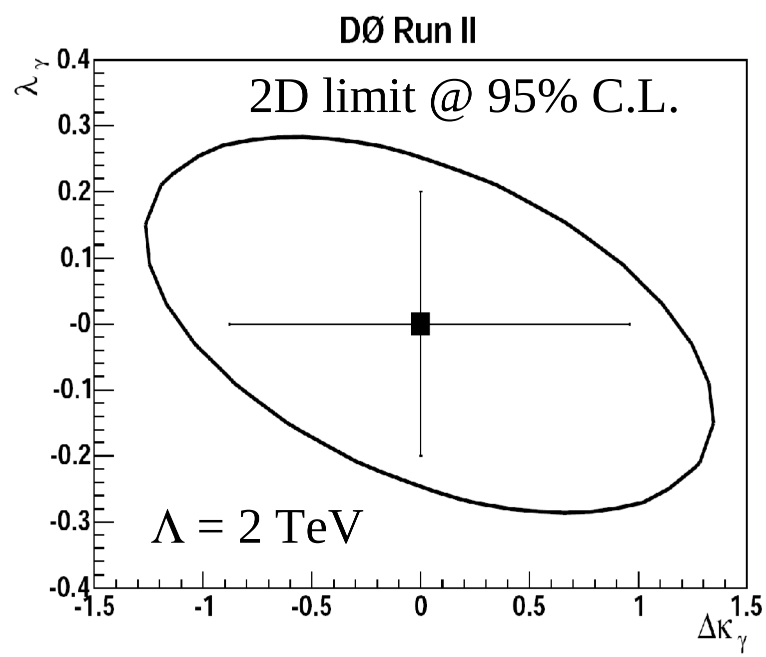
Λ= 2 TeV

$-0.88 < \Delta\kappa_\gamma < 0.96$

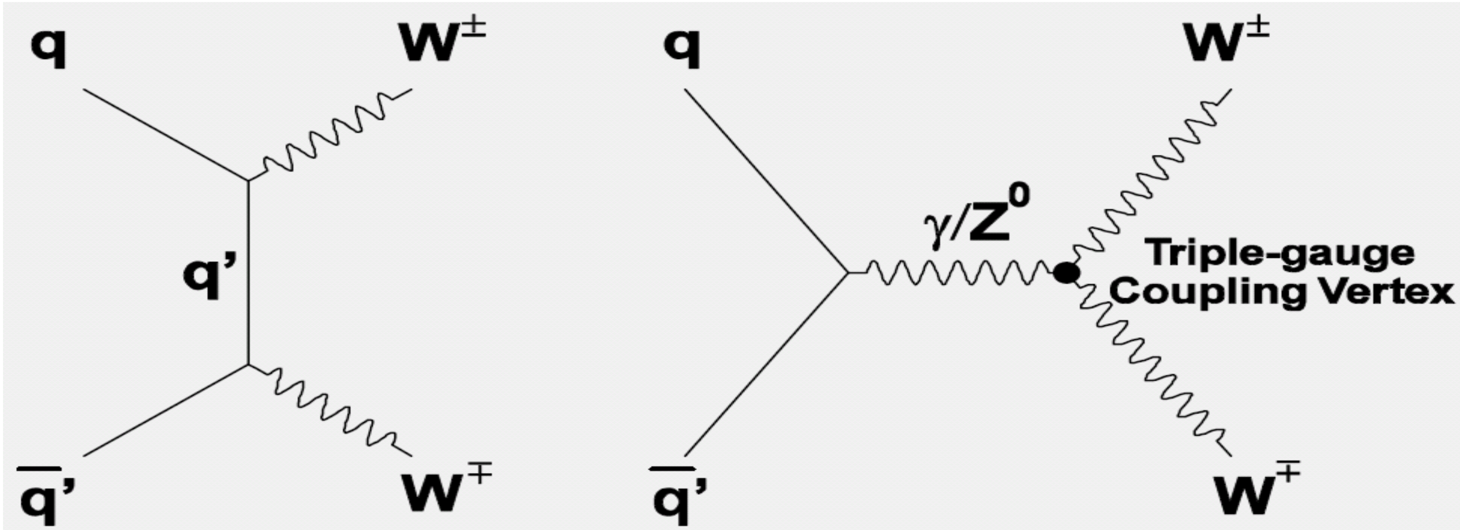
$-0.20 < \lambda_\gamma < 0.20$

Submitted to PRD Rapid Comm.

hep-ex/0503048



WW



- Sensitive to WWZ /WWγ
- Background for Higgs, NP searches
- Dilepton analysis: ee, μμ, eμ
  - Clean, but low branching fraction

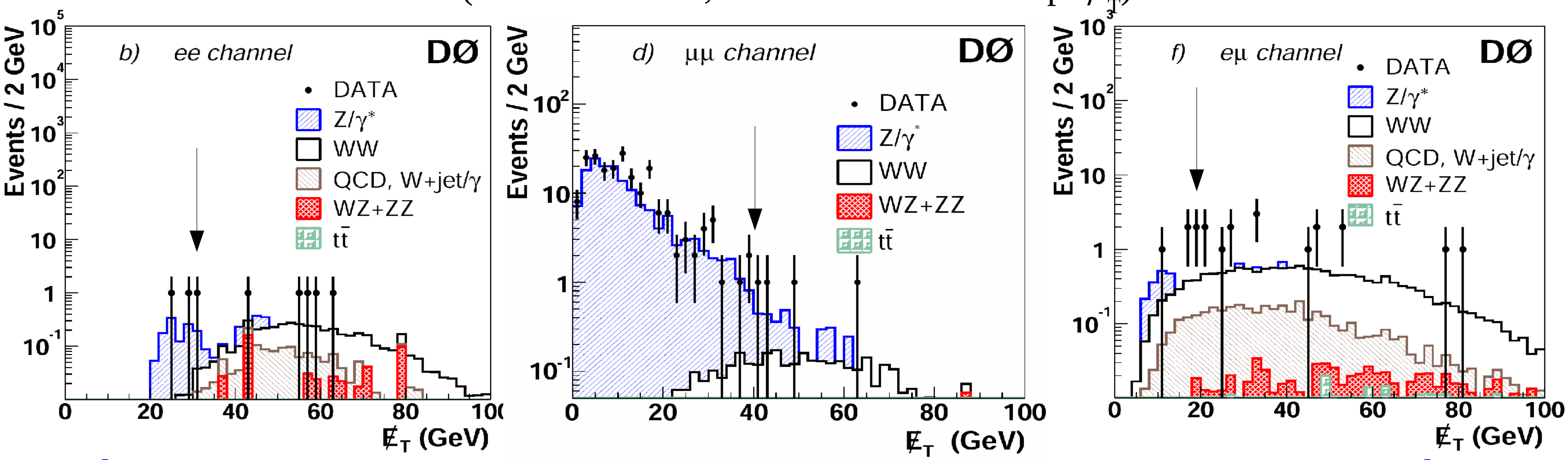
- Main Backgrounds:
  - W+j/γ, dijet
  - Drell-Yan
  - top pairs
  - WZ, ZZ

WW Event Selection

	ee	μμ	eμ	description
p_T	| ← $p_T(1)>20$ GeV, $p_T(2)>15$ GeV → |			preselection
$\not{E}_T$ (in GeV)	> 30	> 40	> 20	
η	$\eta_e < 3$	$\eta_\mu < 2$	$\eta_e < 3; \eta_\mu < 2$	preselection
$\not{E}_T^{SC}$ (in $\sqrt{\text{GeV}}$)	< 15	---	< 15	rejects W+j, DY
$\Delta\varphi$	---	< 2.4	----	rejects DY
H_T (in GeV)	< 50	< 100	< 50	rejects top pairs
M_T^{min} (in GeV)	> 60	---	>20	rejects DY, dijet
Mass (in GeV)	M< 76; M>106	20<M<80	$M_{ll}<61$; $M_{ll}>121$ (for $N_l \geq 3$)	rejects DY, WZ, ZZ

Good Agreement between data and signal+background MC

(Plots show data, MC after all cuts except $\not{E}_T$)



WW Results

Main Syst. Uncertainties:

- μ, e resolutions
- lepton efficiencies

Main background (after cuts)

- ee, eμ: dijet
- $\mu\mu$: $Z/\gamma^* \to \mu\mu$

	ee	$\mu\mu$	eμ
$\int \mathcal{L}$ (pb^{-1})	252	224	235
Efficiency(%)	8.71 ± 0.13	6.22 ± 0.15	15.4 ± 0.2
Expected Background	2.30 ± 0.21	1.95 ± 0.41	3.81 ± 0.17
Expected WW	3.42 ± 0.05	2.10 ± 0.05	11.1 ± 0.1
# Candidates	6	4	15

$$\sigma(p\bar{p}\to W^+W^-) = 13.8^{+4.3}_{-3.8}(\text{stat})^{+1.2}_{-0.9}(\text{sys})\pm 0.9(\text{lum})\text{ pb}$$

SM* 12.0-13.5 pb

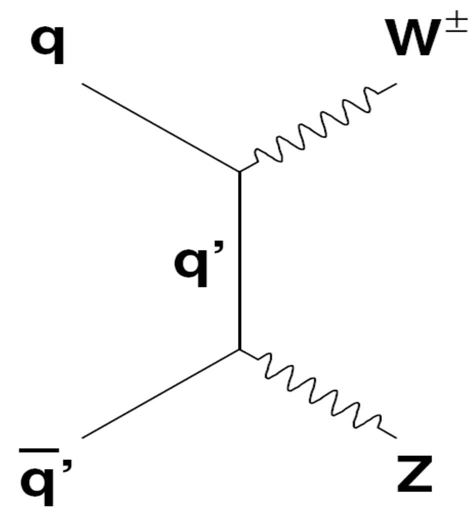
*Ohnemus (1991), (1994), and Cambell & Ellis (1999).

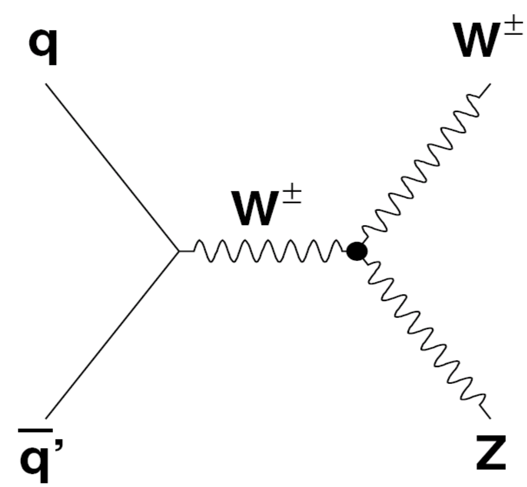
hep-ex/0410066
Accepted by PRL

WZ

- Only sensitive to WWZ coupling

  (WW is sensitive to WWZ and WWγ)
- WZ unavailable at e^+e^- colliders
- Important background for searches
- Search for WZ to 3 leptons + $\not{E}_T$
  - eee, eeμ, eμμ, μμμ
  - ~Only SM process with trilepton signature
  - Distinct, but rare
    - $\sigma(p\bar{p}\rightarrow WZ)$~4.0 pb at Run II Energy
    - Branching fraction ~1.5%





WZ Event Selection

James Degenhardt in E7

Z Selection:

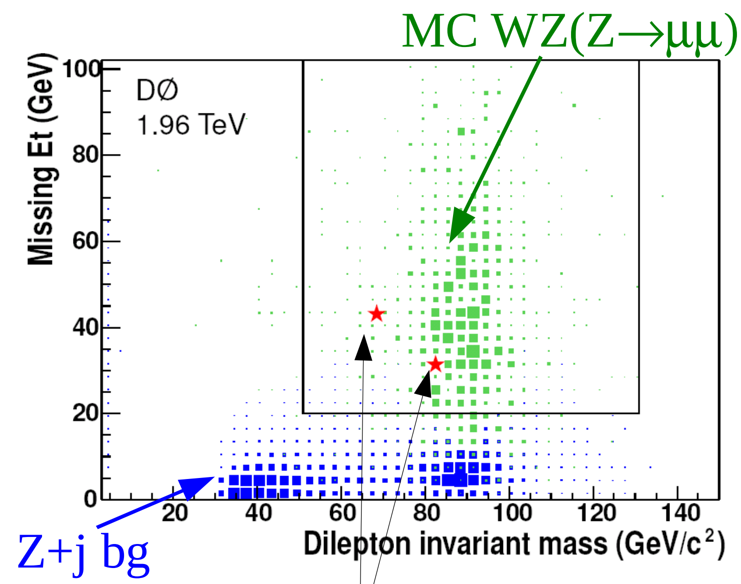
- 2 isolated ee/μμ with p_T>15 GeV that reconstruct a Z mass

W Selection:

- Isolated e or μ with p_T>15 GeV
- $\not{E}_T$>20 GeV

Main backgrounds:

- Z+X (X=j, γ, or Z)



Find 3 events: 2 μμμ and 1 eee

Est. total bg: 0.71

Cross section limit
σ(WZ+X) < 13.3 pb (95% C.L.)

P(0.71 bkgd)⟶ 3 signal events is 3.5%

Interpreting the events as signal+background gives:

Cross section $\sigma(WZ) = 4.5^{+3.5}_{-2.6}$ pb

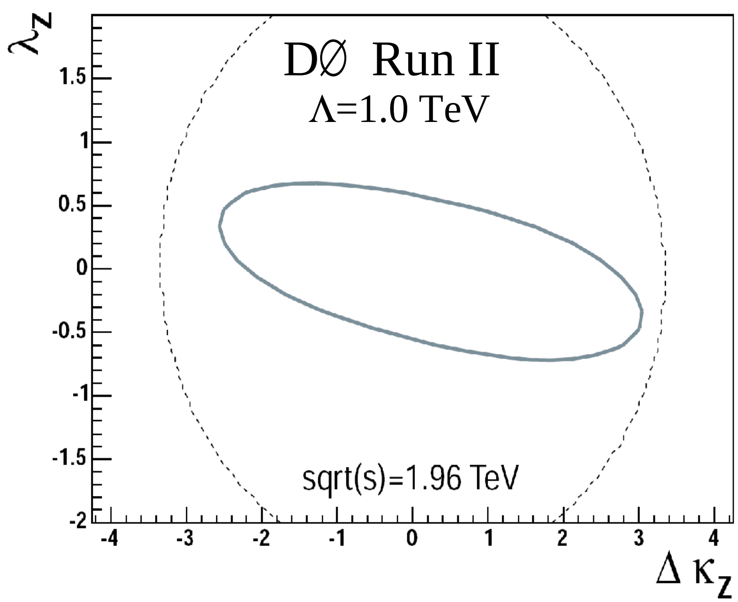
SM* 3.7 ± 0.1 pb

*Cambell and Ellis (1999)

WWZ Anomalous Trilinear Couplings

- Best limits in WZ final states
- First 2D limits in $\Delta\kappa_Z$ vs λ_Z using WZ
- Best limits available on g_1^Z, $\Delta\kappa_Z$ and λ_Z from direct, model-independent measurements
- DØ RunII 1D limits are ~factor of 2-3 better than our RunI limits

1D Limits at 95% C.L.
$\Lambda = 1.0$ TeV
$-0.53 < \lambda_Z < 0.56$
$-0.57 < \Delta g_1^Z < 0.76$
$-2.0 < \Delta\kappa_Z < 2.4$



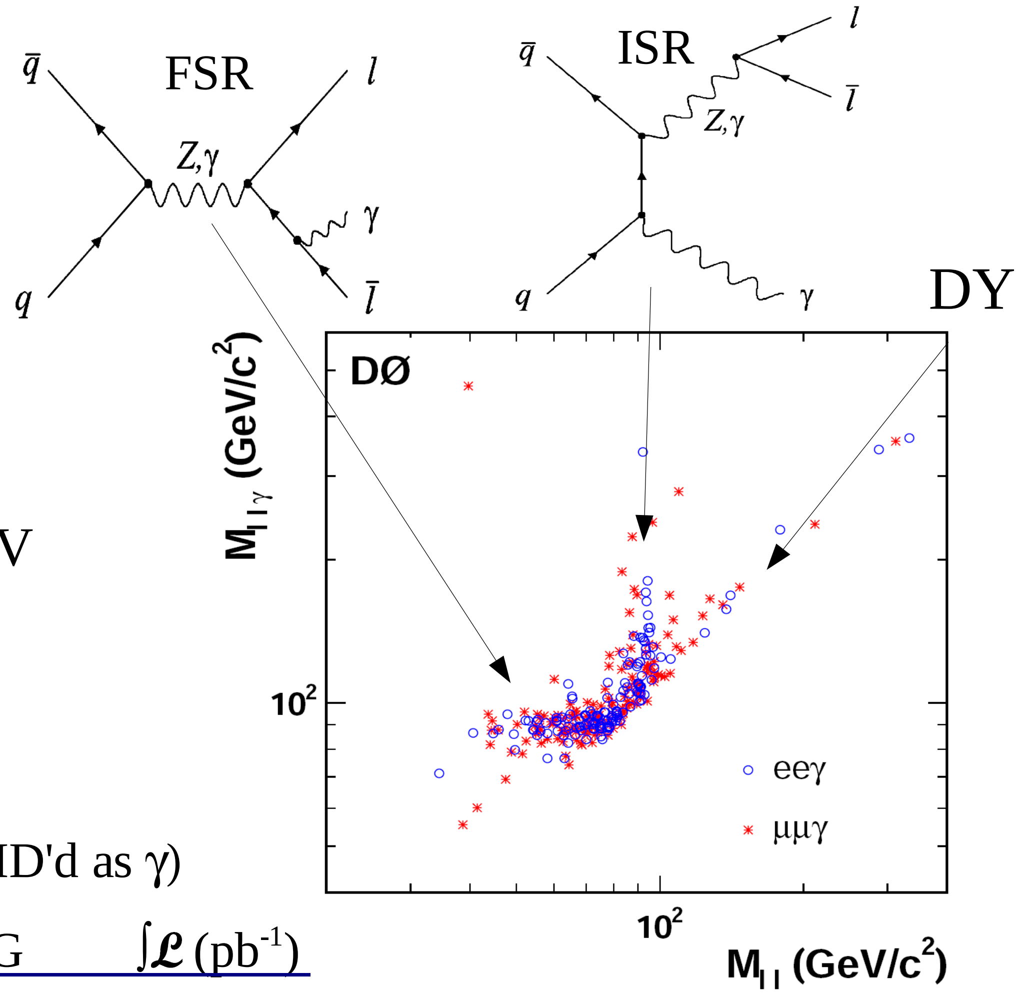
Inner contours: DØ 2D limits
Outer contours: unitary boundary

James Degenhardt in E7

hep-ex/0504019 Submitted to PRL

Zγ

- ISR and FSR contributions, but no ZZγ or Zγγ in SM
- Look for Z decay to ee or μμ with M(ll)> 30 GeV
  - ee: 2 isolated electrons with p_T>15GeV, p_T>25 GeV
  - μμ: 2 isolated μ with p_T>15 GeV
- Photon: $E_T(\gamma) > 8$ GeV
  $\Delta R(l\gamma) > 0.7$
- Main background is Z+j (jet misID'd as γ)



channel	Observed	Expected (SM)	BG	$\int\mathcal{L}$ (pb^{-1})
eeγ	138	95.3 ± 4.9	23.6 ± 2.3	320
μμγ	152	126.0 ± 7.8	22.4 ± 3.0	290

Yurii Maravin in E7

$$\sigma(p\bar{p} \rightarrow Z\gamma) = 4.2 \pm 0.4_{stat+sys} \pm 0.3_{lum}\ \text{pb}$$

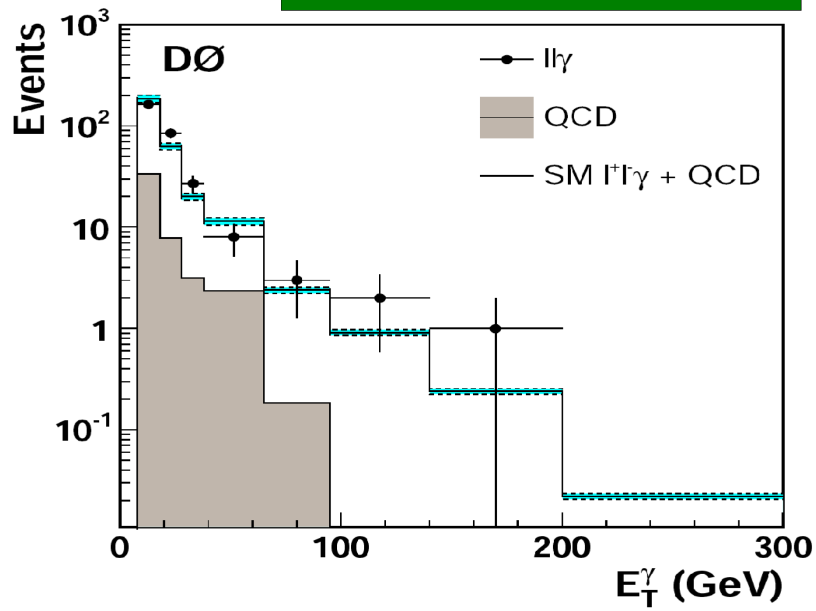
SM: 3.9 ± 0.2 pb (Baur, Han, & Ohnemus 1998)

hep-ex/0502036
Submitted to PRL

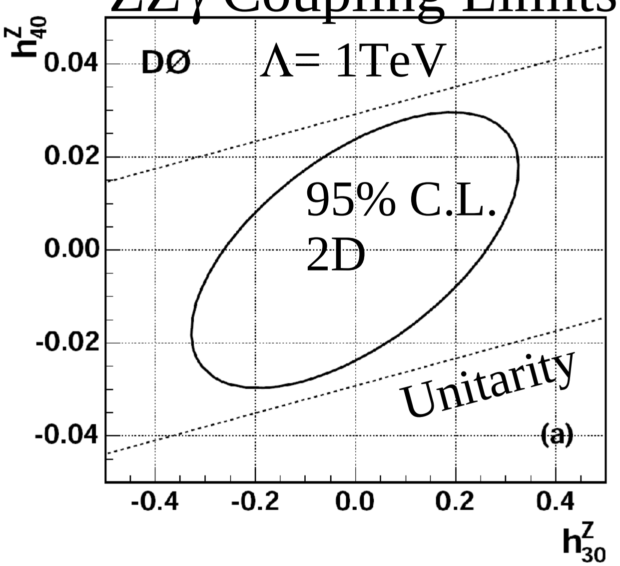
Zγ Anomalous Couplings

Yurii Maravin in E7

- Perform binned likelihood fit to $E_T(\gamma)$ spectrum (similar method as used for Wγ)
- L_{eff} has 8 coupling parameters
  - $h^V_{10}, h^V_{20}, h^V_{30}, h^V_{40}$ (V=Z,γ)
  - All = 0 in SM



ZZγ Coupling Limits

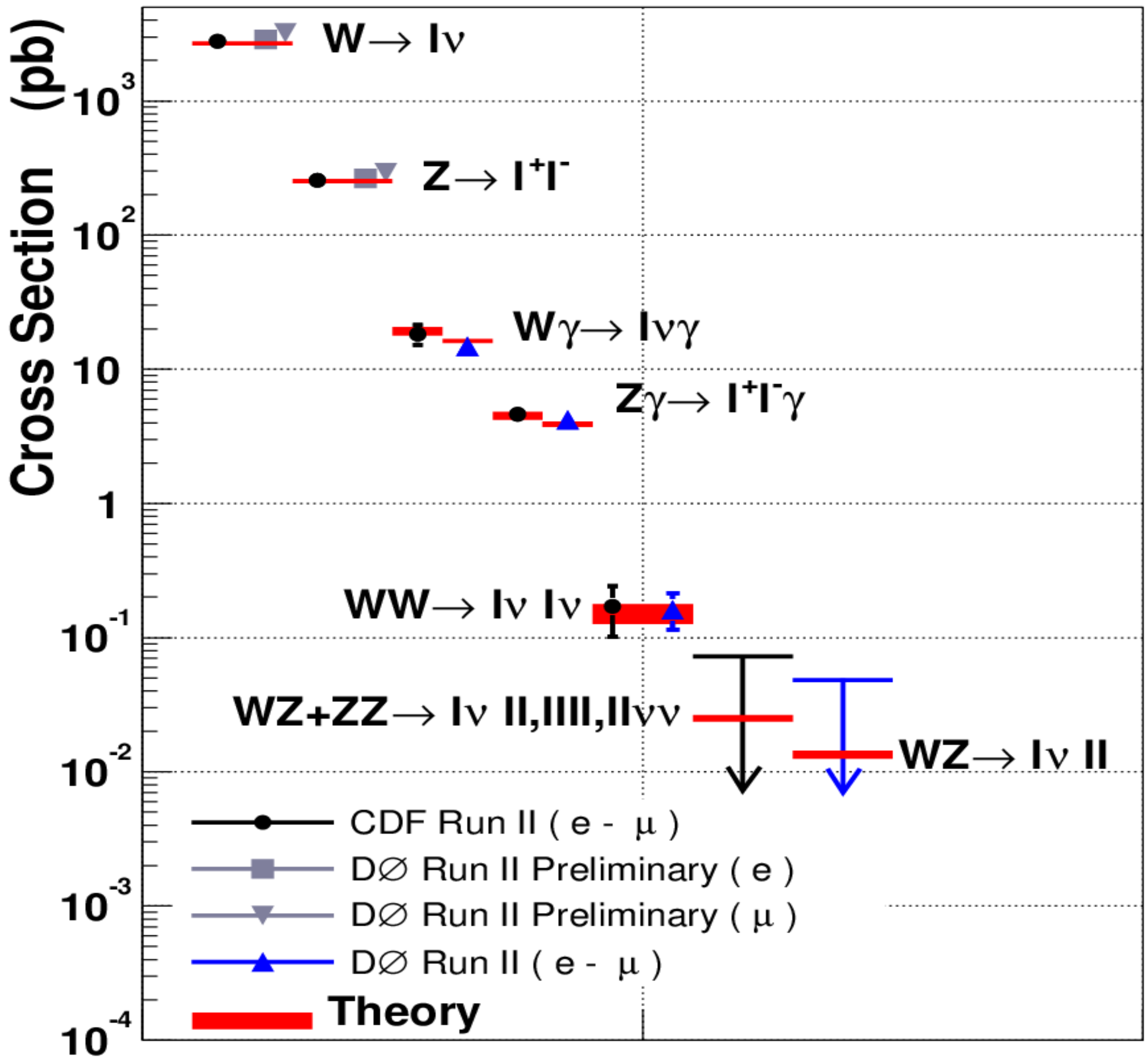


1D Limits, 95% C.L.
Λ= 1TeV
$\lvert h^\gamma_{10,30}\rvert < 0.23$
$\lvert h^\gamma_{20,40}\rvert < 0.019$
$\lvert h^Z_{10,30}\rvert < 0.23$
$\lvert h^Z_{20,40}\rvert < 0.020$

Most stringent limits to date

hep-ex/0502036
Submitted to PRL

DiBoson Summary



Summary

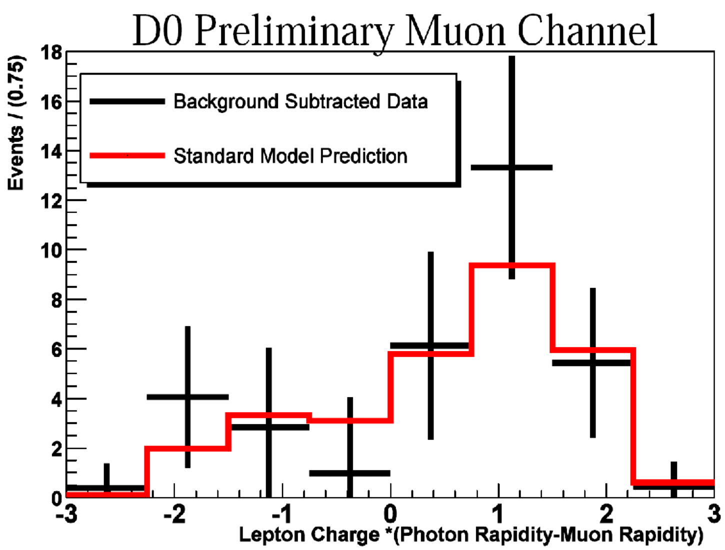
- Presented a collection of Electroweak Physics results from DØ in Run II
  - W/Z to leptons cross sections
  - First measurement of $\sigma(p\bar{p}\rightarrow Z\rightarrow\tau\tau)$
  - Differential cross sections
  - Diboson cross sections and Anomalous Coupling limits
- Measurements in agreement with Standard Model
- Run II at the Tevatron is progressing well
  - Present results are based on a fraction of Run II expected $\int\mathcal{L}$

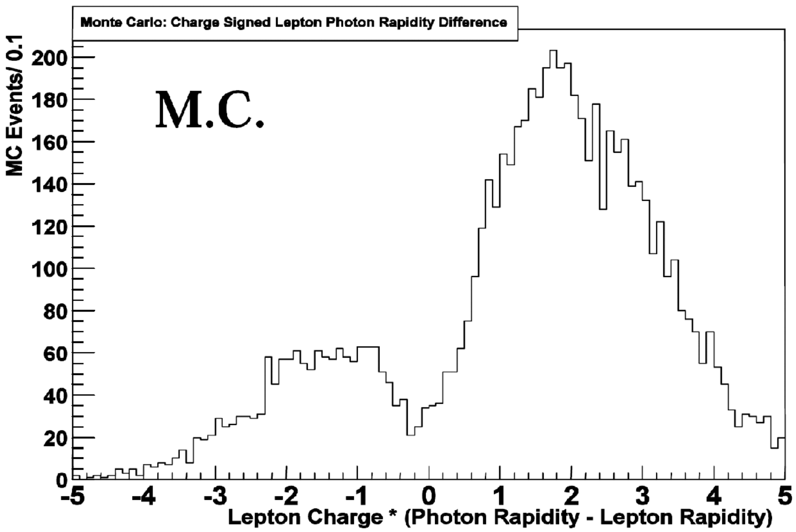
Just Beginning to Tap into the Potential of Run II

Backup Slides

Wγ Radiation Amplitude Zero

- For COS(θ*), the angle between incoming quark and photon in the Wγ rest frame, = −1/3, SM has "amplitude zero".
- For events w/ M_T(cluster)>90 GeV/c^2. One could guess the Wγ rest frame. We use charge-signed $\Delta\eta(l,\gamma)$





- We plot the background-subtracted muon data vs. MC $\Delta\eta(l,\gamma)$ => hints of the Rad. Zero.
- It will help to extend the eta-coverage of electrons and especially of photons.